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MEMOIR ON METEORITES.

A DESCRIPTION

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OF

FIVE NEW METEORIC IRONS,

WITH SOME THEORETICAL CONSIDERATIONS ON THE ORIGIN OF METEORITES, BASED ON THEIR PHYSICAL AND CHEMICAL CHARACTERS.

By J. LAWRENCE SMITH, M.D.,
Professor of Chemistry in the Medical Department of the University of Louisville.

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(Read before the American Association for the Advancement of Science, April, 1854.)

1. *Meteoric Iron from Tazewell County, East Tennessee.**

This meteorite was placed in my possession through the kindness of Prof. J. B. Mitchell of Knoxville, in the month of August, 1853. It was found by a son of Mr. Rogers living in that neighborhood, while engaged in ploughing a hill-side; his attention was drawn to it by its sonorous character. As it very often happens among the less informed, it was supposed to be silver or to contain a large portion of that metal. With some difficulty the mass was procured by Prof. Mitchell, and passed over to me. Nothing could be ascertained as to the time of its fall; it is stated among the people living near where the meteorite was found, that a light has been often seen to emanate from and rest upon the hill, a belief that may have had its foundation in the observed fall of this body.

The weight of this meteorite was fifty-five pounds. It is of a flattened shape, with numerous conchoidal indentations, and three annular openings passing through the thickness of the mass near

* Notice of the discovery of this iron was given by me in 1853.—J. L. S.

the outer edge. Two or three places on the surface are flattened, as if other portions were attached at one time, but had been rusted off by a process of oxydation that has made several fissures in the mass so as to allow portions to be detached by the hammer; although when the metal is sound the smallest fragment could not be thus detached, it being both hard and tough. Its dimensions are such that it will just lie in a box 13 inches long, 11 inches broad and 5½ inches deep. The accompanying figure gives a correct idea of the appearance of this meteorite.

1.

The exterior is covered with oxyd of iron, in some places so thin as hardly to conceal the iron, in other places a quarter of an inch deep. Its hardness is so great that it is almost impossible to detach portions by means of a saw. Its color is white, owing to the large amount of nickel present; and a polished surface when acted on by hot nitric acid displays in a most beautifully regular manner the Widmannstättian figures. The specific gravity taken on three fragments, selected for their compactness and purity, is from 7·88 to 7·91.

The following minerals have been found to constitute this meteorite: 1st. *Nickeliferous iron*, forming nearly the entire mass. 2nd. *Protosulphuret of iron*, found in no inconsiderable quantity on several parts of the exterior of the mass. 3d. *Schreibersite*, found more or less mixed with the pyrites and in the crevices of the iron, in pieces from the thickness of the blade of a penknife to that of the minutest particles. 4th. *Olivine;* two or three very small pieces of this mineral have been found in the interior of the iron. 5th. *Protochlorid of iron;* this mineral has been found in this meteorite *in the solid state*, which I believe is the first observation of this fact; it was found in a crevice

that had been opened by a sledge hammer, and in the same crevice Schreibersite was found. Chlorid of iron is also found deliquescing on the surface ; some portions of the surface are entirely free from it, while others again are covered with an abundance of rust arising from its decomposition.

Besides the above minerals two others were found, one a siliceous mineral, the other in minute rounded black particles ; both, however were in too small quantity for any thing like a correct idea to be formed of their composition.

The different minerals that admitted of it, were examined chemically, and the following are the results:

1. *Nickeliferous Iron.*—The specific gravity of this iron is as already stated, from 7·88 to 7·91. It is not readily acted on by any of the acids in the cold; nitric acid, either concentrated or dilute, has no action on it until heated to nearly 200° Fahr., when the action commences, and continues with great vigor even after the withdrawal of heat. With reference to the action of sulphate of copper, it is *passive;* although when immersed in a solution of sulphate of copper, and allowed to remain for several hours, the latter metal deposits itself in spots on the surface of the iron.

Thorough digestion in hot nitric acid dissolves the iron completely. When boiled with hydrochloric acid the iron dissolves with the liberation of hydrogen, leaving undissolved the Schreibersite; but by long continued action this latter is also dissolved with the evolution of phosphuretted hydrogen.

The following ingredients were detected on analysis of two specimens:

	1.	2.
Iron,	82·39	83·02
Nickel,	15·02	14·62
Cobalt,	·43	·50
Copper,	·09	·06
Phosphorus,	·16	·19
Chlorine,		·02
Sulphur,		·08
Silica,	·46	·84
Magnesia,		·24
	98·55	99·57

Tin and arsenic were looked for, but neither of those substances detected. The magnesia and silica are doubtless combined, probably in the form of olivine, and disseminated in minute particles through the iron. The phosphorus is in combination with a given portion of iron and nickel, forming Schreibersite; the ·16 per cent. of phosphorus corresponds to 1·15 of Schreibersite: so the metal mass may be looked on as composed of

Nickeliferous iron 98·97, Schreibersite 1·03=100·00.

The composition of the nickeliferous iron corresponds to five atoms of iron and 1 of nickel.

Iron,	5 atoms,	82·59
Nickel,	1 "	17·41=100·00

2. *Protosulphuret of Iron.*—This variety of sulphuret of iron found with meteorites is usually designated as magnetic pyrites, leaving it to be inferred that its composition is the same as that of the terrestrial variety. Without alluding to the doubt among some mineralogists as to the true composition of the terrestrial magnetic pyrites, I have only to say that most careful examination of the sulphuret detached from the meteorite in question proves it to be a protosulphuret; a conclusion to which Rammelsberg had already come, with reference to the pyrites of the Seelasgen iron, which latter pyrites I have also examined, confirming the results of Rammelsberg.

This pyrites encrusts some portion of the iron, and in places is mixed with a little Schreibersite. It presents no distinct crystalline structure, has a grey metallic lustre, and a specific gravity of 4·75. The Seelasgen pyrites gave me for specific gravity 4·681.

The specimen of pyrites in question gave, on analysis:

Iron 62·38, sulphur 35·67, nickel 0·32, copper *trace*, silica 0·56, lime 0·08=98·91.

The formula Fe S requires sulphur 36·36, iron 63·64.

The magnetic property of this mineral is far inferior to that possessed by Schreibersite.

3. *Schreibersite.*—It is found disseminated in small particles through the mass of the iron, and is made evident by the action of hydrochloric acid; it is also found in flakes of little size, inserted as it were into the iron; and owing to the fact that in many parts where it occurs chlorid of iron also exists, this last has caused the iron to rust in crevices, and on opening these, Schreibersite was detached mechanically. This mineral as it exists in the meteorite in question, so closely resembles magnetic pyrites that it can be readily mistaken for this latter substance; and I feel confident in asserting that a great deal of the so-called magnetic pyrites associated with various masses of meteoric iron, will upon examination, be found not to contain a trace of sulphur, and will on the contrary prove to be Schreibersite that can be easily recognised by the characters to be fully detailed a little farther on.

Its color is yellow or yellowish-white, sometimes with a greenish tinge; lustre metallic; hardness 6; specific gravity 7·017. No regular crystalline form was detected; its fracture in one direction is conchoidal. It is attracted very readily by the magnet, even more so than magnetic oxyd of iron; it acquires polarity and retains it. I have a piece $\frac{3}{10}$ of an inch long, $\frac{2}{10}$ of an inch broad, and $\frac{1}{20}$ of an inch thick, which has retained its polarity over six months; unfortunately the polarity was not tested immediately when it was detached from the iron, and not until it had come in contact with a magnet, so that it cannot be pronounced as originally polar.

Before the blowpipe it melts readily, little blisters forming on the surface from the escape of *chlorine*, and blackens. The magnet is a most ready means of distinguishing the Schreibersite from the pyrites commonly found in meteoric irons; for although the pyrites is attracted by the magnet, it is necessary that the latter should be brought quite near to it for the effect to be produced; whereas if the particles exposed to the magnet be Schreibersite, they will be attracted with almost the readiness of iron filings.

Hydrochloric acid acts exceedingly slowly on this mineral when pulverized, with the formation of phosphuretted hydrogen. Nitric acid acts more vigorously, and readily dissolves it when finely pulverized. The composition of this substance has, in all cases but one, been made out from the residue of meteoric iron, after having been acted on by hydrochloric acid, which accounts for the great variation in the statements of the proportion of its constituents.

Mr. Fisher examined pieces of Schreibersite detached from the Braunau iron, with the following results: Iron 55·430, nickel 25·015, phosphorus 11·722, chrome 2·850, carbon 1·156, silex 0·985=98·158.

The results of my analyses do not differ very materially from this; they are as follows:

	1.	2.	3.
Iron,	57·22	56·04	56·53
Nickel,	25·82	26·43	28·02
Cobalt,	0·32	0·41	0·28
Copper,	*trace*	not estimated.	
Phosphorus,	13·92		14·86
Silica,	1·62		
Alumina,	1·63		
Zinc,	*trace*	not estimated.	
Chlorine,	0·13		
	100·66		99·69

Nos. 1 and 2 were separated mechanically from the iron. No. 3 chemically. The silica, alumina and lime were almost entirely absent from No. 3, and in the other specimen they are due to a siliceous mineral that I have found attached in small particles to the Schreibersite. There is no essential difference in my results, yet in neither instance do I suppose the mineral was obtained perfectly pure; although enough so, it is believed, to furnish the correct chemical formula; and, as from what has been previously said, Schreibersite will be found to exist in larger quantities than it was suspected, it will not be long before the question of the uniformity of its composition will be settled, a point of interest bearing upon the theoretical consideration of meteoric stones.

The formula of Schreibersite, I consider to be Ni_2Fe_4P.

		Per cent.
Phosphorus,	1 atom	15·47
Nickel,	2 "	29·17
Iron,	4 "	55·36

This mineral, although not usually much dwelt upon when speaking of meteorites, is decidedly the most interesting one associated with this class of bodies, even more so than the nickeliferous iron. It has no representative in genus or species among terrestrial minerals, and is one possessed of highly interesting properties. Although among terrestrial minerals phosphates are found, not a single phosphuret is known to exist; so true is this, that with our present knowledge, if any one thing could convince me more strongly than another of the non-terrestrial origin of any natural body, it would be the presence of this or some similar phosphuret. It is commonly alluded to as a residue from the action of hydrochloric acid upon meteoric iron; when in fact it exists in plates and fragments of some size in almost all meteoric iron; and there is reason to believe that it is never absent from any of them in some form or other: what is meant by "some size" is, that it is in pieces large enough to be seen by the naked eye, and to be detached mechanically.

In an examination of the meteoric specimens in the Yale College Cabinet, more than half of them have been discovered to contain Schreibersite visible to the eye, that had been considered pyrites. Among them, the large Texas meteorite was examined, and although none was visible on the surface, a small fragment of the same mass given me by Prof. Silliman, contains a piece of Schreibersite of over a grain weight.

The reason why it has not attracted more attention, arises from its resemblance to pyrites; I will therefore state a ready manner of telling whether it be such or not.

Detach a small fragment, and hold a magnet capable of sustaining five or six ounces or more, within half an inch or an inch of the fragment, if it be Schreibersite it will be attracted with great readiness; the magnetic pyrites requiring a very close approximation of the magnet before attracted. This, with some little experience, becomes a ready method of separating the two. It is not, however, to be expected that this method alone, is to satisfy us, when other means can be appealed to for distinguishing this mineral; the following is one which is readily accomplished with the smallest fragment (half a milligramme). Melt in a small loop of platinum wire, a little carbonate of soda, add the smallest fragment of nitrate of soda and the piece of mineral, hold the mixture in the flame of a lamp for two or three minutes; place the bead of soda in a watch glass, add a little water and filter; to the filtrate add a drop or two of acid to neutralize the excess of carbonate of soda; evaporate nearly to dryness; add a drop of ammonia, and then a drop of ammoniacal sulphate of magnesia, when the double phosphate of magnesia and ammonia will show itself, and the crystalline form will be recognised under the microscope. If the piece examined be several milligrammes in weight,

the operation can be carried on in a small platinum capsule. This reaction can also be had by acting on the mineral, however small the piece, by aqua-regia, evaporate until only a little of the liquid is left, add a little tartaric acid, then a drop or two of ammonia to supersaturate the acid, and lastly a little ammoniacal sulphate of magnesia, when the crystals of the double phosphate of magnesia and ammonia will appear.

4. *Protochlorid of Iron.*—In breaking open one of the fissures of this meteoric iron, a small amount of a green substance was obtained, that was easily soluble in water, and although not analyzed quantitatively, it left no doubt upon my mind as to its being protochlorid of iron; and the manner of its occurrence gave strong evidence of its being an original constituent of the mass, and not formed since the fall of the mass. Chlorid of iron was apparent on various parts of the iron by its deliquescence on the surface.

2. *Meteoric Iron from Campbell County, Tenn.*

This meteorite was discovered in July, 1853, in Campbell County, Tennessee, in Stinking Creek, which flows down one of the narrow valleys of the Cumberland mountains. It was found by a Mr. Arnold in the channel of this stream, and having been obtained by Prof. Mitchell of Knoxville, he kindly presented it to me. It is a small oval mass $2\frac{1}{4}$ inches long, $1\frac{3}{4}$ broad, and $\frac{3}{4}$ thick, with an irregular surface and several cavities perforating the mass. It was covered with a thin coat of oxyd; and on one half of it chlorid of iron was deliquescing from the surface, while on another portion there was a thin siliceous coating.

The iron composing the mass was quite tough, highly crystalline, and exhibited small cavities on being broken, resembling very much in this respect, as well as in many other points, the Hommony Creek iron; a polished surface, when etched, exhibited distinct irregular Widmannstättian figures.

The weight is $4\frac{1}{2}$ ounces. Specific gravity, 7·05. The lowness of the specific gravity is accounted for by its porous nature. Composition—

Iron,	97·54
Nickel,	0·25
Cobalt,	0·6
Copper, too small to be estimated.	
Carbon,	1·50
Phosphorus,	0·12
Silica,	1·05
	100·52

Chlorine exists in some parts in minute proportion. The amount of nickel, it will be seen is quite small, but its composition is nevertheless perfectly characteristic of its origin.

3. *Meteoric Iron from Coahuila, Mexico.*

This meteorite was brought to this country by Lieut. Gouch, of the U. S. Army, he having obtained it at Saltillo. It was said to have come from the Sancha estate, some fifty or sixty miles from Santa Rosa in the north of Coahuila; various accounts were given of the precise locality, but none seemed very satisfactory. When first seen by Lieut. Gouch, it was used as an anvil, and had been originally intended for the Society of Geography and Statistics in the city of Mexico. It is stated that where this mass was found, there are many others of enormous size; these stones, however, it is well known, are to be received with many allowances. Mr. Weidner, of the mines of Freiberg, states that near the southwestern edge of the Balson de Mapimi, on the route to the mines of Parral, there is a meteorite near the road of not less than a ton weight. Lieut. Gouch also states that the intelligent but almost unknown Dr. Berlandier, writes in his journal of the commission of limits, that at the Hacienda of Venagas there was (1827) a piece of iron that would make a cylinder one yard in length with a diameter of ten inches. It was said to have been brought from the mountains near the Hacienda. It presented no crystalline structure, and was quite ductile.

The meteoric mass in question, which is at the Smithsonian Institution, is of the form represented in the figure, and one well

2.

adapted for an anvil. Its weight is 252 lbs., and from several flattened places, I am led to suppose that pieces have become detached. The surface, although irregular in some places, is rather smooth, with only here and there thin coatings of rust, and, as might be expected, but very feeble evidence of chlorine, and that only on one or two spots on the surface. Specific gravity 7·81. It is highly crystalline, quite malleable, and not difficult to cut with the saw. Its surface etched with nitric acid, presents the Widmannstättian figures, with a finely specked surface between

the lines, resembling the representation we have of the etched surface of Hauptmannsdorf iron. Schreibersite is visible in the iron, but so inserted in the mass, that it cannot be readily detected by mechanical means. Hydrochloric acid leaves a residue of beautifully brilliant patches of this mineral.

Subjected to analysis, it was found to contain

Iron,	95·82
Cobalt,	·35
Nickel,	3·18
Copper, minute quantity not estimated.	
Phosphorus,	0·24
	99·59

Which corresponds to

Nickeliferous Iron,	98·45
Schreibersite,	1·55
	100·00

The iron is remarkably free from other constituents. It is especially interesting as the largest mass of meteoric iron in this country next to the Texas meteorite at Yale College.

4. *Meteoric Iron from Tucson, Mexico.*

We have had several accounts of meteoric masses which exist at Tucson; Dr. J. L. LeConte having made them known some few years ago. Since that time Mr. Bartlett, of the Boundary Commission, has seen them and made a drawing of one which he has kindly allowed me the use of, as well as the manuscript* notice of them, which is however, quite brief. This mass is used for an anvil, resembles native iron, and weighs about six hundred pounds. Its greatest length is five feet. Its exterior is quite smooth, while the lower part which projects from the larger leg is very jagged aud rough. It was found about twenty miles distant towards Tubac, and about eight miles from the road where we are told are many larger masses. The following figure (3) represents the appearance of that meteorite.

Since my communication last April, I have obtained fragments of the meteorite from Lieut. Jno. G. Parke, of the U. S. Topographical Engineers, who cut them from the mass at Tucson, and to whose kindness I feel much indebted.

Some of the fragments were entirely covered with rust, and in some parts, little blisters existed, arising from chlorid of iron. Portions of the broken surface retain their metallic lustre untarnished. The Widmannstättian figures are very imperfectly developed, owing to the porous nature of the iron, the pores of which are filled with a stony mineral. The specific gravity taken on three specimens were 6·52—6·91—7·13. The last was the most compact and free from stony particles that could be found, and upon that the chemical examination was made.

* Since this was communicated to the American Association for the Advancement of Science, Mr. Bartlett's valuable and instructive work, entitled "Personal Narrative of Explorations in Texas, New Mexico, California, Sonora, and Chihuahua," has been published in two handsome octavo volumes, by the Messrs. Appleton's, New York: and we are indebted to the publishers for the use of Mr. Bartlett's fine cuts on the following pages.—J. L. S.

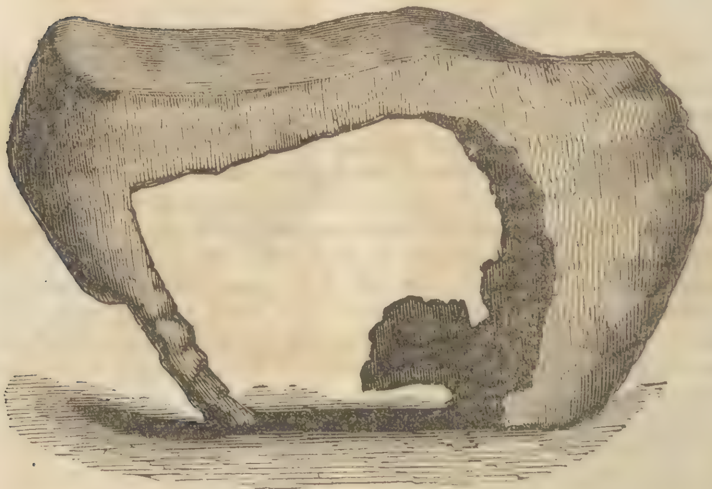
On examination it is seen to consist of two distinct parts, metallic and stony; the latter was only in minute particles, yet it was impossible, among the specimens at my disposal, to find a piece that was without it. On analysis, the following ingredients were found:

Iron,	85·54
Nickel,	8·55
Cobalt,	·61
Copper,	·03
Phosphorus,	·12
Chromic oxyd,	·21
Magnesia,	2·04
Silica,	3·02
Alumina.	*trace*
	100·12

Which represent the following minerals:

Nickeliferous iron,	93·81
Chrome iron,	·41
Schreibersite,	·84
Olivine,	5·06
	100·12

3.



Some few particles of olivine were separated mechanically, and readily recognised as such under the magnifying glass in connection with the action of acids, which readily decompose it, furnishing silica and magnesia. Some of the olivine is in a pulverulent condition, resembling that of the Atacama iron. The nickeliferous iron of this Tucson meteorite also resembles that of the Atacama iron; calculated from the above results, it consists of

Iron 90·91, nickel 8·46, cobalt·63, copper, *trace*=100·00.

This meteorite* is one of much interest, and it is to be hoped that some of our enterprising U. S. Topographical Engineers

* Since my notice of this meteorite, Prof. C. U. Shepard has published (Am. Journal of Science, Nov. 1854) an account of it, not aware of my communication to the Am. Assoc. He seems inclined to think that the stony material might be chladnite, although he could form no definite conclusion on this head. From what has

will yet be able to persuade the owners to part with it and bring it to this country.

5. *Meteoric Iron of Chihuahua, Mexico.*

For the description of this meteorite, I am indebted to the manuscript of Mr. Bartlett, and had hoped to have obtained a fragment of it for examination from Dr. Webb, who detached pieces from the mass; but when applied to, they were no longer

4.

in his possession. It exists at the *Hacienda de Conception*, about ten miles from Zapata. "The form is irregular. Its greatest height is forty-six inches; greatest breadth thirty-seven inches; circumference in thickest part eight feet three inches. Its weight as given by Senor Urquida, is about three thousand eight hundred and fifty-three pounds. It is irregular in form, as seen by the figure; and one side is filled with deep cavities, generally round and of various dimensions. At its lower part, as it now stands, is a projecting leg, quite similar to the one on the meteorite at Tucson. The back or broadest part is less jagged than the other portions, and contains fewer cavities, yet, like the rest, is very irregular."

been said in the text, it will be seen to be olivine, the chladnite of the Bishopville stone not being attacked by acid, or only to a very feeble extent, by boiling sulphuric acid. And I would here remark that from some investigations just made, chladnite is likely to prove a pyroxene.—J. L. S.

SOME THEORETICAL CONSIDERATIONS CONNECTED WITH METEORITES.

Under this head no mention will be made of the phenomena accompanying the fall of meteorites, as their light, noise, bursting, and their black coating; which arise after the bodies have entered the atmosphere, and are brought about by its agency. This omission will affect in no way the theoretical views under consideration, and the introduction of these particulars would uselessly increase the length of this memoir.

The lessons to be learned from meteorites, both stony and metallic, are probably not as much appreciated as they ought to be; we are usually satisfied with an analysis of them and surmises as to their origin, without due consideration of their physical and chemical characters.

The great end of science is to generalize facts that are observed. Thus terrestrial gravitation has been extended to the solar system, and in fact to the whole universe. The astronomer by his discoveries only proves the universality of this one law of nature operating on matter; he has found no evidence that any other force pertaining to terrestrial matter displays itself in a similar manner in other spheres. However true and self-evident it may appear that all matter in space is under the same laws, be they those of gravitation, cohesion, chemical affinity, etc., it is none the less interesting to have the fact proved, and meteorites when looked upon as bringing these proofs acquire additional interest.

Meteorites studied in the way just mentioned, lead us to the inference that the materials of the earth are exact representatives of the materials of our system; for up to the present time, no element has been found in a meteorite that has not its counterpart on the earth; or, if we are not warranted in making such a broad assumption, we certainly have the proof, as far as we may ever expect to get it, that materials of other portions of the universe are identical with those of our earth.

Meteorites also show that the *laws of crystallization* in bodies foreign to the earth, are the same as those affecting terrestrial matter, and in this connection we may instance pyroxene, olivine and chrome iron, affording, in their crystalline form, angles identical with those of terrestrial origin.

But perhaps of all the interesting facts under this head developed by meteorites, is the universality of the laws of chemical affinity, or the truth, that all the laws of chemical combination and atomic

constitution are to be equally well seen in extra-terestrial and terrestrial matter; so that were Dalton or Berzelius to seek for the atomic weights of iron, silica or magnesia they might learn them as well from meteoric minerals as from those taken from the bowels of the earth. The atomic constitution of meteoric anorthite or of pyroxene is the same as that which exists in our own rocks.

Keeping in view then the physical and chemical characters of meteorites, I propose to offer some theoretical considerations. which, to be fully appreciated, must be followed step by step. These views are not offered, because they individually possess particular novelty; it is the manner in which they are combined, to which especial attention is called.

Physical Characteristics to be noted in Meteorites.—The first physical characteristic to be noted is their form. No masses of rock, however rudely detached from a quarry, or blasted from the side of a mountain, or ejected from the mouth of a volcano, would present more diversity of form than meteoric stones: they are rounded, cubical, oblong, jagged, flattened, and in fine they present a great variety of fantastic shapes. Now the fact of form I conceive to be a most important point for consideration in regard to the origin of these bodies; as the form alone is strong proof that the individual meteorites have not always been cosmical bodies; for had they been, their form must have been spherical or spheroidal; as this is not so it is reasonable to suppose that at one time or another, they must have constituted a part of some larger mass. But as this subject will be taken up again, I pass to another point—namely the crystalline structure, more especially that of the iron; and the complete separation in nodules, in the interior of the iron, of sulphuret and phosphuret of the metals constituting the mass. When this is properly examined, it is seen that these bodies must have been in a plastic state for a great length of time; for nothing else could have determined such crystallization as we see in the iron, and allow such perfect separation of sulphur and phosphorus from the great bulk of the metal, combining only with a limited portion to form particular minerals; and did we aim to imitate such separation by artificial processes, we could only hope to do it by retaining the iron in a plastic condition for a great length of time. Also, no other agent than fire can be conceived of by which this metal could be kept in the condition requisite for the separation.

If these facts with reference to the crystalline structure be admitted, the natural suggestion is that they could only have been thus heated while a part of some large body.

Another physical fact, worthy of being noticed here, is the manner in which the metallic iron and stony parts are often interlaced and mixed; as in the Pallas and Atacama irons, where nickeliferous iron and olivine in nearly equal portions (by bulk)

are intimately mixed; so that when the olivine is detached the iron resembles a very coarse sponge. This is an additional fact in proof of the great heat to which the meteorites must have been submitted; for with our present knowledge of physical laws, there is no other way in which we can conceive that such a mixture of iron and olivine could have been produced.

Other physical points might be noticed, but as they are familiar to all, and would add nothing to the theoretical considerations, they will be passed over.

Mineralogical and Chemical points to be noted in Meteorites.—The rocks or minerals of meteorites are not of a sedimentary character, not such as are produced by the action of water. This is obvious to any one who will examine these bodies. A mineralogist will also be struck with the thin dark-colored coating on the surface of the stony meteorites. The coating, in most, if not in all, instances, is of atmospheric origin, being acquired after the meteorite enters the atmosphere, and as such, no further notice will be taken of it; but I will proceed at once to notice the most interesting peculiarities under this head. First of all, metallic iron, alloyed with more or less nickel and cobalt, is of constant occurrence in meteorites,—with but three or four exceptions,—in some instances constituting the entire mass; at other times disseminated in fine particles through stony matter. The existence of this highly oxydizable mineral in its metallic condition is a positive indication of a scarcity, or total absence, of oxygen (in its gaseous state or in the form of water) in the locality from whence it came.

Another mineralogical character of significance is, that the stony portions of the meteorites resemble the older igneous rocks, and in even a more striking manner, the volcanic rocks belonging to various active and extinct volcanoes. It is useless to dwell on this fact; as it is one well known to all mineralogists who may have examined this matter; and none have given more especial attention to it than Rammelsberg, who, in a paper published in 1849, details his examination of a great variety of lavas, and traced the perfect parallelism between them and stony meteorites. He showed that the Juvenas stone has the same constitution as the Thjorsa lava of Heckla, both consisting substantially of augite and anorthite, even in nearly the same relative proportions: while the Chateau Renard and Nordhausen stones, have labradorite replacing the anorthite; and the Blansko, Chantonnay and Utrecht stones have oligoclase as the feldspar, and resemble the lavas of Ætna, Stromboli and the newer lavas of Heckla.

The inference to be drawn from the last character is very evident; it is highly significative of the igneous origin of these bodies, and of an igneous action similar to that now existing in our volcanoes.

Yet another point of resemblance to certain of our terrestrial igneous rocks is the presence of metallic iron; for lately Mr. Andrews has proved the existence of metallic iron in basaltic rocks; but this will not be insisted on; as the quantity of iron discovered in basaltic rocks is so minute as only to be detected by the most delicate means of investigation.

Ever since the labors of Howard in 1802, the chemical constitution of meteorites have attracted much attention, more especially the elements associated in the metallic portion; and although we find no new elements, still their association, so far as yet known, is peculiar to this class of bodies. Thus nickel is a constant associate of iron in meteorites, (if we except the Walke Co., Ala., and Oswego, N. Y., meteorites,upon whose claims to meteoric origin there yet remains some doubt) ; and although cobalt and copper are mentioned only as occasional associates in my examination of near thirty known meteorites (in more than one-half of which these constituents were not mentioned), I have found both of the last mentioned metals as constantly as the nickel. With our more recent method of separating cobalt from nickel, very accurate and precise results can be obtained as relates to the cobalt ; the copper exists always in so minute proportion that the most careful manipulation is required to separate it.

Another element frequently, but not always, mentioned as associated with the iron, is phosphorus. Here again my testing of thirty specimens lead me to a similar generalization concerning phosphorus; namely, that no meteoric iron is to be expected without it ; my examination has extended as well to the metallic particles separated from the stony meteorites as to the meteoric irons proper. It may be even further stated that, in most instances, the phosphorus was traceable directly to the mineral Schreibersite.

These four elements then, Iron, Nickel, Cobalt and Phosphorus, I consider remarkably constant ingredients; First in the meteoric irons proper, and secondly in the metallic particles of the stony meteorites ; there being only some three or four meteorites among hundreds that are known, in which they are not recognized.

As regards the combination of these elements, it is worthy of remark that no one of them is associated with oxygen, although all four of them have strong affinity for this element, and are never found (except copper) in the earth uncombined with it, except where some similar element (as sulphur, &c.) supplies its place.*

The inference of the absence of oxygen in a gaseous condition, or in water, is drawn from such substances as iron and nickel being in their metallic state, as has been just mentioned ;

* The traces of iron found in basaltic rock already alluded to, forms too insignificant an exception to be insisted on.—J. L. S.

but it must not be inferred that oxygen is absent in all forms at the place of origin of the meteorites; for the silica, magnesia, protoxyd of iron, &c., contain this element. The occurrence of one class of oxyds and not another would indicate a limited supply of the element oxygen; the more oxydizable elements as silicon, magnesium, &c., having appropriated it in preference to the iron.

Many other elements worthy of notice might be mentioned here, and some of them for aught we know may be constant ingredients; but in the absence of strong presumption at least on this head, they will be passed over; as those already mentioned suffice for the support of all theoretical views to be advanced.

I cannot, however, avoid calling attention to the presence of *carbon* in certain meteorites; for, although its existence is denied by some chemists, it is nevertheless a fact that can be as easily established as the presence of the nickel. The interest to be attached to it, is due to the fact that it is so commonly regarded in the light of an organic element. It serves to strengthen the notion that carbon can be of pure mineral origin; for no one would be likely to suppose that the carbon found its way into a meteorite either directly or indirectly from an organic source.

Having thus noted the predominant physical, mineralogical and chemical characteristics of meteorites I pass on to the next head.

Marked points of similarity in the Constitution of Meteoric Stones.—Had this class of bodies not possessed certain properties distinguishing them from terrestrial minerals, much doubt would even now be entertained of their celestial origin, and various would be the explanations, made even in those cases where the bodies were seen to fall and afterwards collected. Chemistry has entirely dissipated all doubts in the matter, and now, an examination in the laboratory of the chemist is entitled to more credit than evidence from any other source in pronouncing on the meteoric origin of a body. No question need be asked as to whether it was seen to fall, or whether this or that rock or mineral exists in the neighborhood where it may have been collected. The reagents of the chemist alone are unerring indications that suffice to set aside all caviling in the matter.

It is the object of this part of the paper to explain more prominently perhaps than has yet been done, how it is that chemistry pronounces with such unerring certainty on the celestial origin of certain bodies; and I propose to go even a step farther, and see if the chemical constitution of the meteorites can indicate from what part of the heavens they may have come.

When the mineralogical and chemical composition of these bodies ~~are~~ regarded, the most ordinary observer will be struck

with the wonderful family likeness running through them all, however unlike at first sight. There will be seen to be three great divisions of meteoric bodies (omitting three or four), namely —metallic; stony with small particles of metal; and a mixture of metallic and stony in which the former predominates, as in the Pallas and Atacama meteorites.

As regards external appearances, these three classes differ in a very marked manner from each other; The *meteoric iron* being ordinarily of a compact structure, more or less corroded externally, and when cut showing a dense structure with most of the peculiarities of pure iron, only a little harder in texture and whiter in color. The *stony meteorites* are usually of a grey or greenish grey color, granular structure, readily broken by a blow of the hammer, and exteriorly are covered with a thin coating of fused material. The *mixed meteorite* presents characters of both of the above; a large portion of it is constituted of the kind of iron already mentioned, cellular in its character, and the cells filled up with stony materials, similar in appearance to those constituting the second class. t

Although there are some instances of bodies of undoubted meteoric origin not properly falling under either of the above three heads, still they will be seen upon close investigation not to interfere in any way with the general conclusions that are attempted to be arrived at; for these constituents are represented in the stony materials of the second class, from which their only essential difference consists in the absence of metallic particles.

If we now examine chemically the three classes mentioned, we find them all possessed of certain common characteristics that link them together and at the same time separate them from every thing terrestrial. Take first the metallic masses: and in very many instances, in some fissure or cavity, exposed by sawing or otherwise, stony materials will frequently be found, and a stony crystal is sometimes exposed; now examine the composition of these, and then compare the results with what may be known of the stony meteorites; and in every instance, it will agree with some mineral or minerals found in this latter class, as olivine or pyroxene, most commonly the former; but in no instance is it a mineral not found in the stony meteorites. If these last, in their turn, be examined, differing vastly in their appearance from the metallic meteorites, they will, with but two or three exceptions, be found to contain a malleable metal identical in composition with the metal constituting the metallic meteorites.

As to those mixed meteorites in which the metallic and stony portions seem to be equally distributed; their two elements are but representatives of the two classes just described. Examined in this way there will be no difficulty in tracing the same signa-

ture on them all, endorsing the above as their true character, and almost serving to tell us whence they came. They may emphatically be said to have been linked in their origin by a chain of iron.

There is one mineral which there is every reason to believe constantly accompanies the metallic portions, and which may be regarded as a most peculiar mark of difference between meteorites and terrestrial bodies. It is the mineral *Schreibersite* (see first part of this memoir) to which the constant presence of phosphorus in meteoric iron is due. This mineral, as already remarked, has no parallel on the face of the globe, whether we consider its specific or generic character; there being no such thing as phosphuret of iron and nickel or any other phosphuret found among minerals. These facts render the consideration of Schreibersite one of much interest; running as it probably does through all meteorites, and forming another point of separation between meteorites and terrestrial objects.

Another striking similarity in the composition of meteorites is the limited action of oxygen on them. In the case of the purely metallic meteorites we trace an almost total absence of this element. In the stony meteorites, the oxygen is in combination with silicon, magnesium, &c., forming silica, magnesia, &c., that combine with small portions of other substances to form the predominant earthy minerals of meteorites. When iron is found in combination with oxygen, it is found in its lowest state of oxydation as in the protoxyd of the olivine and chrome iron, and as magnetic oxyd.

Without going further into detail as regards the similarity of composition of meteorites, they will be seen to have as strongly marked points of resemblance as minerals coming from the same mountain, I might almost say from the same mine; and it is not asking much to admit their having a *common centre of origin,* and that whatever the body from which they originate, it must contain no uncombined oxygen and I might even add none in the form of water.

What is this centre of origin? Physics does not point it out; and although the chemist cannot explore the elementary constitution of any other great celestial bodies than the earth, he can examine those smaller celestial masses which come to the earth, and from his results stand on a firmer basis for theoretical conclusions.

Origin of Meteoric Stones.—In taking up the theoretical considerations of the origin of meteoric stones, it is of the utmost consequence, to reflect well before we confound shooting stars and meteoric stones as all belonging to the same class of bodies; a view entertained by many distinguished observers. It is doubtless owing to the fact of their having been confounded that but

little advance has been made in settling upon the origin of these bodies; in fact, owing to this manner of viewing the subject, observers such as Arago, Bissel, Olbers and others have turned away from the original conception of the origin of meteoric stones to views of a different character based on observations of the shooting stars.

It may be a broad assumption to start with, that there is not a single evidence of the identity of shooting stars (as exemplified by the periodical meteors of August and November) and those meteors which give rise to meteoric stones, and this conclusion is one arrived at by as full an examination of the subject as I am capable of making.* Some of the prominent reasons for such a conclusion will be mentioned.

Were shooting stars and meteoric stones the same class of bodies, it is natural to suppose that the fall of the latter would be most abundant when the former are most numerous. In other words these periodic occurrences of shooting stars in August and November and more particularly those immense showers that have been sometimes seen, ought to have been attended with the falling of one or more meteoric stones; whereas there is not a single instance on record where these showers have been accompanied with the falling of a meteoric stone. Again, in all instances where a meteoric body has been seen to fall and has been observed even from its very commencement, it has been alone and not accompanied by other meteors. Very little reflection will serve to convince any one that an objection to the identity of the two classes of bodies based upon the above fact is of great weight.

Another strong objection to considering the bodies of the same nature, is based on the want of proof of their velocities being the same. It is a pretty well established fact that the average velocity of shooting stars is 16½ miles a second, a result arrived at by different observers, and doubtless a close approximation to the truth; as from the constant occurrence of shooting stars, thousands of observations may be made with comparative ease by different observers noting the same stars: not so with meteoric stones, these occurrences being rare, sudden and unexpected, and no two observers being ever prepared to note the data requisite for calculating their velocities; besides I am prepared to prove that the two or three cases of supposed determination of velocities of meteoric stones cannot be considered even gross approximation to the truth: in fact the difficulties in the way are so great that we probably never shall arrive at a knowledge of their

* Prof. D. Olmsted, in a most interesting article on the subject of meteors, to be found in the 26th volume of the Am. Journal of Science, p. 132, insists upon the difference between shooting stars and meteorites, and the time and attention he has devoted to the phenomena of meteors give weight to his opinion..

velocities.* Not even their effect on striking the earth will furnish any data whereby to calculate their velocities before entering the atmosphere; for this medium must offer such enormous resistance to bodies penetrating at great velocities, that these velocities must be reduced to but a fraction of what they originally were; and it is a question whether a body entering our atmosphere at ten miles a second would penetrate the soil to a much greater depth than one entering it at five miles a second; for the increased velocity of the former would cause an increased resistance in the atmosphere, and therefore have received proportionally a greater check before striking the earth.

Another fact tending to prove a dissimilarity between shooting stars and meteoric stones, is that the velocity of no one of the shooting stars has been observed to be so low as to allow of their being considered satellites to the earth; their average velocity is 16½ miles a second and it requires a reduction to less than six miles a second for them to assume a path around the earth. Now, assume what we may as to the original orbit of the meteoric stones, and as to their original velocity—let their orbit be around the sun and their velocity 16 miles a second—there is one thing we know, namely that these bodies do enter our atmosphere, and, it is but right to assume, often pass through the atmosphere without falling to the earth, sometimes passing through the very uppermost portion of that medium, at other times lower. What becomes of their original assumed velocity after this passage? As it can be so checked as to be drawn to the earth's surface, and thus stopped altogether in its passage, their velocities may be changed to any velocity from 16 miles a second to zero, according to the amount of resistance it meets with; and what is equally true in this connection, is, that when the velocity falls below six miles a second (or thereabouts) they can no longer escape from the attraction of the earth and resume their solar orbit, but must revolve as a satellite around the earth until ultimately brought to its surface by repeated disturbances.

The deduction from the above fact, is as follows: that as the most correct observations have never given a velocity of less than

* Under this head I will merely note what is considered one of the best established cases of the determination of velocity of a meteoric stone—namely that of the Weston meteorite the velocity of which Dr. Bowditch estimated to "*exceed three miles a second.*" Mr. Herrick considers the velocity very much greater, and writes among other things what follows. "The length of its path from the observations made at Rutland, Vt., and at Weston was at least 107 miles. This space being divided by the duration of the flight as estimated by two observers, viz., 30 seconds, we have for the meteor's relative velocity about *three and a half miles a second.* The observations made at Wenham, Mass., are probably less exact in this respect and need not be mentioned here. An experienced observer, however intelligent, will give the time ten or even twenty fold too large. One not unversed in science who saw the meteor is confident it could not have been in sight as long as ten seconds." The above is given as a specimen of the uncertain data we are to proceed upon in estimating the velocity of meteoric stones.

nine miles a second to a shooting star, it is reasonable to suppose that none have ever entered our atmosphere; or what is perhaps still more reasonable, that the matter of which they are composed is as subtle as that of Encke's comet; and any contact with even the uppermost limit of the atmosphere, destroys their velocity and disperses the matter of which they are composed. Other grounds might be mentioned for supposing a difference between shooting stars and meteoric stones; and I have dwelt on it thus much, because it is conceived of prime importance in pursuing the correct path that is to lead to the discovery (if it can be made) of their origin. It is also of no small value to the beautiful and probable theory of shooting stars that we should separate every thing from it that may tend to affect its plausibility.

Various theories have been devised to account for their origin. One is that they are small planetary bodies revolving around the sun, and that at times they become entangled in our atmosphere lose their orbital velocity by the resistance of the atmosphere and are finally attracted to the earth. They are also supposed to have been ejected from the volcanoes of the moon: and lastly they are considered as formed from particles floating in the atmosphere. The exact nature of this last theory, is understood by reading the views of Prof. C. U. Shepard, as expressed in an interesting report on meteorites published in 1848. The author* says—" The extra-terrestrial origin of meteoric stones and iron masses, seems likely to be more and more called in question with the advance of knowledge respecting such substances, and as additions continue to be made to the connected sciences. Great electrical excitation is known to accompany volcanic eruptions, which may reasonably be supposed to occasion some chemical changes in the volcanic ashes ejected; these being wafted by the ascensional force of the eruption into the regions of the magneto-polar influence, may there undergo a species of magnetic analysis. The most highly magnetic elements, (iron, nickel, cobalt, chromium, &c.,) or compounds in which these predominate, would thereby be separated, and become suspended in the form of metallic dust, forming those columnar clouds so often illuminated in auroral displays, and whose position conforms to the direction of the dipping needle. While certain of the diamagnetic elements, (or combinations of them,) on the other hand, may under the control of the same force be collected into different masses, taking up a position at right angles to the former, (which Faraday has shown to be the fact in respect to such bodies,) and thus produce those more or less regular arches, transverse to the magnetic meridian, that are often recognized in the phenomena of the aurora borealis.

* I must in justice to Prof. Shepard say that, since his paper was written, he has informed me that he no longer entertains these views; and I would now omit the criticism of them did they not exist in his memoir uncontradicted and also were they not views still entertained by some.

"Any great disturbance of the forces maintaining these clouds of meteor-dust, like that produced by a magnetic storm, might lead to the precipitation of portions of the matter thus suspended. If the disturbance was confined to the magnetic dust, iron masses would fall; if to the diamagnetic dust, a non-ferruginous stone; if it should extend to both classes simultaneously, a blending of the two characters would ensue in the precipitate, and a rain of ordinary meteoric stones would take place.

"The occasional raining of meteorites might therefore on such a theory, be as much expected, as the ordinary deposition of moisture from the atmosphere. The former would originate in a mechanical elevation of volcanic ashes and in matter swept into the air by tornadoes, the latter from simple evaporation. In the one case, the matter is upheld by magneto-electric force; in the other, by the law of diffusion which regulates the blending of vapors and gases, and by temperature. A precipitation of metallic and earthy matter would happen on any reduction of the magnetic tension; one of rain, hail or snow, on a fall of temperature. The materials of both originate in our earth. In the one instance they are elevated but to a short distance from its surface, while in the other, they appear to penetrate beyond its farthest limits, and possibly to enter the inter-planetary space; in both cases, however, they are destined, through the operation of invariable laws, to return to their original repository."

This theory, coming as it does from one who is justly entitled to high consideration, from the fact of the special attention he has given to the subject of meteorites, may mislead; and for that reason objections will be advanced which will doubtless entirely set aside this notion of terrestrial origin, and to this end I would consider two fundamental principles of it. First of all it must be proved that terrestrial volcanoes contain all the varieties of matter found in the composition of meteoric bodies; there is no doubt that many of the varieties are ejected from volcanoes, as olivine, &c.; but then the principal one, nickeliferous iron has never in a single instance been found in the lava or other matter coming from volcanoes although frequently sought for.

But the physical obstacles are a still more insuperable difficulty in the way of adopting this theory. In the first place it is considered a physical impossibility for tornadoes or other currents of air to waft matter, however impalpable, "beyond the farthest limits of the earth and possibly into interplanetary space." Again if magnetic and diamagnetic forces cause the particles to coalesce and form solid masses, by the cessation of those forces the bodies would crumble into powder. Another strong physical objection to the theory is, that as the consolidation of these masses is expected to take place in "magneto-polar regions" their fall should only be in those portions of the earth, for like rain and hail (to

which the consolidation of these bodies are assimilated in this theory) they should fall perpendicularly or nearly so, from their points of condensation. And lastly (under the head of physical objections) how can bodies so formed be precipitated in such very oblique directions as many are known to have, and that too from East to West and not from the North.

We pass on to a concise statement of some of the chemical objections to this theory of atmospheric origin, and if possible, they are more insuperable than the last mentioned. Contemplate for a moment the first meteorite described in this paper;—here is a mass of iron of about sixty pounds of a most solid structure, highly crystalline, composed of nickel and iron chemically united, containing in its centre a crystalline phosphuret of iron and nickel, and on its exterior surface a compound of sulphur and iron also in atomic proportions, and then see if the mind can be satisfied in supposing that the dust wafted from the crater of a volcano into the higher regions of the atmosphere, could *in a few moments of time* be brought together by any known forces so as to create the body in question. However finely divided this volcanic dust might be, it can never be subdivided into atoms, a state of things that must exist to form bodies in atomic proportions, where no agency is present to dissolve or fuse the particles concerned. One other objection and I am done with this theory. The particles of iron and nickel supposed to be ejected from the volcano, must pass from the heated mouth of a crater ascend through the oxygen of the atmosphere without undergoing the slightest oxydation, for if there be any one thing which marks the meteorites more strongly than any other it is the freedom of the masses of iron from oxydation except on the surface. But a still more remarkable abstinence from oxydation would be the ascent of the particles of phosphorus to form the Schreibersite traceable in so many meteorites.

Having noticed the prominent objections to this theory I pass on to consider in as few words as possible the other two theories.

A very commonly adopted theory of the origin of meteoric bodies, is that they are small planetary bodies revolving around the sun, one portion of their orbit approaching or crossing that of the earth, and from the various disturbing causes to which these small bodies must necessarily be subjected, their orbits are constantly undergoing more or less variation, until intersected by our atmosphere, when they meet with the most serious derangement and fall to the earth's surface in whole or in part; this may not occur in their first passage through the atmosphere, but repeated obstructions in this medium at different times must ultimately bring about the result. In this theory their origin is supposed to be the same as that of other planetary bodies, and they are regarded as always having had an individual cosmical existence. Now, how-

ever reasonable the admission of this orbital motion immediately before and for some time previous to their contact with the earth, the assumption of their original cosmical origin would appear to have no support in the many characteristics of meteoric bodies as enumerated some pages back. The form alone of these bodies is any thing but what ought to be expected from a gradual condensation and consolidation; all the chemical and mineralogical characters are opposed to this supposition. If the advocates of this theory do not insist on the last feature of it, then the theory amounts to but little else than a statement that meteoric stones fall to us from space while having an orbital motion. In order to entitle this planetary theory to any weight it must be shown, how bodies, formed and constructed as these are, could be other than fragments of some very much larger mass.

As to the existence of meteoric stones in space, travelling in a special orbit prior to their fall, there can be but little doubt when we consider their direction and velocity; their composition proving them to be of extra-terrestrial origin. This, however, only conducts in part to their origin, and those who will examine them chemically will feel convinced that the earth is not the first great mass that meteoric stones have been in contact with, and this conviction is strengthened when we reflect on the strong marks of community of origin so fully dwelt upon.

It is then in consideration of what was the connection of these bodies prior to their having an independent motion of their own that this memoir will be concluded.

Lunar Origin of Meteoric Stones.—It only remains to bring forward the facts already developed, to prove the plausibility of this origin of meteorites.

It is a theory that was proposed as early as 1660 by an Italian philosopher, Terzago, and advanced by Olbers in 1795, without any knowledge of its having been before proposed; it was sustained by Laplace with all his mathematical skill from the time of its adoption to his death; it was also advocated on chemical grounds by Berzelius, whom I have no reason to believe ever changed his views in this matter; and to these we have to add the following distinguished mathematicians and philosophers: Biot, Brandes, Poisson, Quetelet, Arago and Benzenberg who have at one time or another advocated the Lunar origin of meteorites.

Some of the above astronomers abandoned the theory, among them Olbers and Arago; but they did not do so, from any supposed defect in it, but from adopting the assumption that shooting stars and meteorites were the same; and on studying the former and applying the phenomena attendant upon them to meteorites, the supposed lunar origin was no longer possible.

On referring to the able researches of Sears C. Walker on the periodical meteors of August and November (Trans. Am. Phil.

Soc., Jan., 1841), that astronomer makes the following remarks about Olbers's change of views. "In 1836, Olbers, the original proposer of the theory of 1795, being firmly convinced of the correctness of Brandes's estimate of the relative velocity of meteors, renounces his *selenic* theory, and adopts the *cosmical* theory as the only one which is adequate to explain the established facts before the public."

For reasons already stated, it appears wrong to assume the identity of meteorites and shooting stars; so that whatever difficulty the phenomena of shooting stars may have interposed in conceiving this or that to have been the origin of meteoric stones, it now no longer exists; and we are fully authorized in forming our conclusions concerning them to the utter disregard of the phenomena of shooting stars. Had Olbers viewed the matter in this light, he would doubtless have retained his original convictions, to which no material objection appears to have occurred to him for forty years.

It is not my object to enter upon all the points of plausibility of this assumed origin, or to meet all the objections which have been urged to it; for most of them have already been ably treated of. The object, now, is simply to urge such points as have been developed in this memoir, that appear to give strength to the lunar theory; they may be summed up under the following heads:

1st. That all meteoric masses have a community of origin.

2nd. At one period they formed parts of some large body.

3d. They have all been subject to a more or less prolonged igneous action corresponding to that of terrestrial volcanoes.

4th. That their source must be deficient in oxygen.

5th. That their average specific gravity is about that of the moon.

From what has been said under the head of common characters of meteorites, it would appear far more singular that these bodies should have been formed separately from each other than that they should have at one time or another constituted parts of the same body; and from the character of their formation, that body should have been of great dimensions. Let us suppose all the known meteorites assembled in one mass, and regarded by the philosopher, mindful of our knowledge of chemical and physical laws. Would it be considered more rational to view them as the great representatives of some one body that had been broken into fragments, or as small specks of some vast body in space that at one period or another has cast them forth? The latter it seems to me is the only opinion that can be entertained in reviewing the facts of the case.

As regards the igneous character of the minerals composing meteorites, nothing remains to be added to what has already

been said: in fact no mineralogist can dispute the great resemblance of these minerals to those of terrestrial volcanoes; they having only sufficient difference in association, to establish that although igneous they are extra-terrestrial. The source must also be deficient in oxygen either in a gaseous condition or combined as in water: the reasons for so thinking have been clearly stated as dependent upon the existence of *metallic iron* in meteorites; a metal so oxydizable, that in its terrestrial associations it is almost always found combined with oxygen and never in its metallic state.

What then is that body which is to claim common parentage of these celestial messengers that visit us from time to time? Are we to look at them as fragments of some shattered planet whose great representatives are the thirty-three asteroids between Mars and Jupiter and that they are "minute outriders of the asteroids" (to use the language of R. P. Greg, Jr., in a late communication to the British Association), which have been ultimately drawn from their path by the attraction of the earth? For more reasons than one this view is not tenable; many of our most distinguished astronomers do not regard the asteroids as fragments of a shattered planet; and it is hard to believe if they were, and the meteorites the smaller fragments, that these latter should resemble each other so closely in their composition; a circumstance that would not be realized if our earth was shattered into a million of masses large and small.

If then we leave the asteroids and look to the other planets, we find nothing in their constitution, or the circumstances attending them, to lead to any rational supposition as to their being the original habitation of the class of bodies in question. This leaves us then but the *moon* to look to as the parent of meteorites, and the more I contemplate that body, the stronger does the conviction grow, that to it all these bodies originally belonged.

It cannot be doubted from what we know of the moon that it is in all likelihood constituted of such matter as compose meteoric stones; and that its appearances indicate volcanic action, which, when compared with the combined volcanic action on the face of the globe, is like contrasting Ætna with an ordinary forge, so great is the difference. The results of volcanic throws and outbursts of lava are seen, for which we seek in vain any thing but a faint picture on the surface of our earth. Again in the support of the present view it is clearly established that there is neither atmosphere nor water on the surface of that body, and consequently no oxygen in those conditions which would preclude the existence of metallic iron.

Another ground in support of this view is based on the specific gravity of meteorites, a circumstance that has not been insisted on; and although of itself possessing no great value, yet in conjunction with the other facts it has some weight.

In viewing the cosmical bodies of our system with relation to their densities, they are divided into two great classes—planetary and cometary bodies (these last embracing comets proper and shooting stars), the former being of dense, and the latter of very attenuated matter; and so far as our knowledge extends, there is no reason to believe that the density of any comet approaches that of any of the planets: this fact gives some grounds for connecting meteorites with the planets. Among the planets there is also a difference, and a very marked one, in their respective densities; Saturn having a density of 0·77 to 0·75, water being 1·0; Jupiter 2·00–2·25; Mars 3·5–4·1; Venus 4·8–5·4; Mercury between 7 and 36; Uranus 0·8–2·9; that of the Earth being 5·67.* If then from specific gravity we are to connect meteorites to the planets, as their mean density is usually considered about 3·0,† they must come within the planetary range of Mars, Earth and Venus. In the cases of the first and last we can trace no connection, from our ignorance of their nature and of the causes that could have detached them.

This reduces us then to our own planet consisting of two parts, the planet proper with a density of 5·76, and the moon with a density of about 3·62.‡ On viewing this, we are at once struck with the relation that these bear to the density of meteorites, a relation that even the planets do not bear to each other.

As before remarked, I lay no great weight on this view of the density, but call attention to it as agreeing with conclusions arrived at on other grounds.

The chemical composition is also another strong ground in favor of their lunar origin. This has been so ably insisted on by Berzelius and others that it would be superfluous to attempt to argue the matter any further here; but I will simply make a comment on the disregard that astronomers usually have for this argument. In the memoir on the periodic meteors by Sears C. Walker, already quoted from, it is stated, "The chemical objection is not very weighty; for we may as well suppose a uniformity of constituents in cosmical as in lunar substances." From this conclusion it is reasonable to dissent; for as yet we are acquainted with the materials of but two bodies, those of the earth and those of meteorites, and their very dissimilarity of constitution is the strongest argument of their belonging to different

* For these estimates of the densities of the Planets, the author is indebted to Prof. Peirce.

† Although the average specific gravity of the metallic and stony meteorites is greater, yet the latter exceeding the former in quantity, the number 3·0 is doubtless as nearly correct as can be ascertained.

‡ Although the densities of the earth and moon differ, these two bodies may consist of similar materials; for the numbers given represent the density of bodies as wholes; the solid crust of the earth for a mile in depth cannot average a density of 3·0.

spheres. In further refutation of this idea it may be asked, Is it to be expected that a mass of matter detached from Jupiter (a planet but little heavier than water) or from Saturn (one nearly as light as cork) or from Encke's comet (thinner than air), would at all accord with each other or with those of the earth. It is far more rational to suppose that every cosmical body, without necessarily possessing elements different from each other, yet are so constituted that they may be known by their fragments. With this view of the matter, our specimens of meteorites are but multiplied samples of the same body, and that body, with the light we now have, appears to have been the moon.

This theory is not usually opposed on the ground that the moon is not able to supply such bodies as the meteoric iron and stone; it is more commonly objected to from the difficulty that there appears to be in the way of this body's projecting masses of matter beyond the central point of attraction between the earth and moon. Suffice it to say, that Laplace, with all his mathematical acumen, saw no difficulty in the way of this taking place; although we know, that he gave special attention to it at three different times during a period of thirty years, and died without discovering any physical difficulty in the way. Also for a period of forty years, Olbers was of the same opinion, and changed his views as already stated for reasons of a different character: and to these two we add Hutton, Biot, Poisson and others whose names have been already mentioned.

Laplace's view of the matter was connected with present volcanic action in the moon, but there is every reason to believe that all such action has long since ceased in the moon. This, however, does not invalidate this theory in the least, for the force of projection and modified attraction to which the detached masses were subjected, only gave them new and independent orbits around the earth. that may endure for a great length of time before coming in contact with the earth.

The various astronomers cited concur in the opinion, that a body projected from the moon with a velocity of about eight thousand feet per second would go beyond the mutual point of attraction between the earth and moon, and already having an orbital velocity may become a satellite of the earth with a modified orbit.

The important question then for consideration is, the force requisite to produce this velocity. The force exercised in terrestrial volcanoes varies. According to Dr. Peters, who made observations on Ætna, the velocity of some of the stones was 1250 feet a second, and observations made on the peak of Teneriffe gave 3000 feet a second. Assuming, however, the former velocity to be the maximum of terrestrial volcanic effects, the velocity with

which the bodies started (stones with a specific gravity of about 3·00) must have exceeded 2000 feet a second to permit of an absorbed velocity of 1250 feet through the denser portions of our atmosphere. Now suppose the force of the extinct volcanoes of the moon to have equalled that of Ætna, the force would have been more than sufficient to have projected masses of matter at a velocity exceeding 8000 feet a second; for, the resistance to be overcome by the projectile force, is the attractive force of the moon, which is from 5 to 6 times less than that of the earth; so that the same projectile force in the two bodies would produce vastly greater velocities on the moon than on the earth, discarding of course atmospheric resistance of which there is none in the moon.*

But doubtless, were the truth of the matter known, the projectile force of lunar volcanoes far exceeded that of any terrestrial volcanoes extinct or recent, and this we infer from the enormous craters of elevation to be seen upon its surface, and their great elevation above the general surface of the moon, with their borders thousands of feet above their centre; all of which, point to the immense internal force required to elevate the melted lava that must have at one time poured from their sides. I know that Prof. Dana in a learned paper on the subject of lunar volcanoes (Am. J. Sci., [2], ii, 375, argues that the great breadth of the craters is no evidence of great projectile force, the pits being regarded as boiling craters where force for lofty projection could not accumulate. Although his hypothesis is ingeniously sustained, still, until stronger proof is urged, we are justified I think in asuming the contrary to be true; for we must not measure the convulsive throes of nature at all periods by what our limited experience has enabled us to witness.

As regards the existence of volcanic action in the moon without air or water, I have nothing at present to do, particularly as those who have studied volcanic action concede that neither of these agents is absolutely required to produce it; moreover, the surface of the moon is the strongest evidence we have in favor of its occurring under those circumstances.

But it may be very reasonably asked, Why consider the moon the source of these fragmentary masses called meteorites? May not smaller bodies, either planets or satellites, as they pass by the earth and through our atmosphere, have portions detached by the mechanical and chemical action to which they are subjected? To this, I will assent, as soon as the existence of that body or those bodies is proved. Are we to suppose that each meteorite falling to the earth is thrown off from a different sphere

* It would require at the moon the same force to produce an *initial* velocity of 8000 feet a second as at the earth; and the difference of rate at the end of the first second would be slight (discarding from consideration the atmosphere).—Eds.

which becomes entangled in the atmosphere? If so, how great the wonder that the earth has never intercepted one of those spheres, and that all should have struck the stratum of air surrounding our globe (some fifty miles in height) and escaped the body of the globe 8000 miles in diameter. It is said that the earth has never intercepted one of these spheres; for if we collect together all the known meteorites, in and out of cabinets, they would hardly cover the surface of a good sized room; and no one of them could be looked upon as the maternal mass upon which we might suppose the others to have been grafted; and this would appear equally true, if we consider the known meteorites as representing not more than a hundredth part of those which have fallen.

If it be conceived that the same body has given rise to them, and is still wending its path through space, only seeming by its repeated shocks with our atmosphere to acquire new vigor for a new encounter with that medium, the wonder will be greater, that it has not long since encountered the solid part of the globe; but still more strange, that its velocity has not been long since destroyed by the resistance of the atmosphere. through which, it must have made repeated crossings of over 1000 miles in extent.

But it may be said that facts are stronger than arguments, and that bodies of great dimensions (even over one mile in diameter) have been seen traversing the atmosphere, and have also been seen to project fragments and pass on. Now of the few instances of the supposed large bodies, I will only analyze the value of the data upon which the Wilton and Weston meteorites were calculated; and they are selected, because the details connected with them are more accessible. The calculations concerning the latter were made by Dr. Bowditch; but his able calculations were based on deceptive data,—and this is stated without hesitation knowing the difficulty admitted by all of making correct observation as to size of luminous bodies passing rapidly through the atmosphere. Experiments, that would be considered superfluous, have been instituted to prove the perfect fallacy of making any but a most erroneous estimate of the size of luminous bodies, by their apparent size; *even when their distance from the observer and the true size of the object are known;* how much more fallacious then, any estimate of size made, where the observer does not know the true size of the body, and not even his distance very accurately.

In my experiments, three solid bodies in a state of vigorous incandescence were used; 1st, charcoal points transmitting electricity; 2nd, lime heated by the oxy-hydrogen blowpipe; 3d, steel in a state of incandescence in a stream of oxygen gas. They were observed on a clear night at different distances, and the body of light (without the bordering rays) compared with the disk of the moon, then nearly full, and 45° above the horizon. With-

out going into details of the experiment the results will be tabulated,

	Actual diam. as seen at 10 in.	Apparent diam. at 100 yds.	Apparent diam. at $\frac{1}{4}$ mile.	Apparent diam. at $\frac{1}{2}$ mile.
Carbon points,	$\frac{3}{10}$ of an inch,	$\frac{1}{2}$ the diam. moon's disk,	3 diam. do.do.	$-3\frac{1}{2}$ diam. do.do
Lime light,	$\frac{4}{10}$ " "	$\frac{1}{3}$ " " " "	2 " "	2 " "
Incandes. steel,	$\frac{2}{10}$ " "	$\frac{1}{4}$ " " " "	1 " "	1 " "

If then the apparent diameter of a luminous meteor at a given distance is to be accepted as a guide for calculating the real size of these bodies the

Charcoal* points	would be 80 feet	in diam.	instead of $\frac{3}{10}$ of an inch.
Lime	" " 50 "	"	" $\frac{4}{10}$ "
The steel globule	" " 25 "	"	" $\frac{2}{10}$ "

It is not in place to enter into any explanation of these deceptive appearances, for they are well known facts, and were tried in the present form only to give precision to the criticism on the supposed size of these bodies. Comments on them are also unnecessary, as they speak for themselves. But to return to the two meteorites under review.

That of Wilton was estimated by Mr. Edward C. Herrick, (Am. Journ. of Science, vol. xxxvii, p. 130) to be about 150 feet in diameter. It appeared to increase gradually in size until *just before the explosion*, when it was at its largest apparent magnitude of $\frac{1}{4}$th the moon's disk—exploded 25° to 30° above the horizon with a heavy report, that was heard about 30 seconds after the explosion was seen. One or more of the obervers saw luminous fragments descend toward the ground. When it exploded, it was three or four miles above the surface of the earth ; immediately after the explosion, it was no longer visible. The large size of the body is made out of the fact of its appearing one-fourth the apparent disk of the moon at about six miles distant. After the experiments just recorded, and easy of repetition, the uncertainty of such a conclusion must be evident ; and it is insisted on as a fact easy of demonstration, that a body in a state of incandescence, (as the ferruginous portions of a stony meteorite,) might exhibit the apparent diameter of the Wilton meteorite at six miles distance, and not be more than a few inches or a foot or two in diameter according to the intensity of the incandescence.†

Besides, if that body was so large, where did it go to after throwing off the supposed small fragments? The fragments were seen to fall, but the great ignited mass suddenly disappeared, at 30° above the horizon, four miles from the earth, when it could

* Estimate made according to a table given by Prof. Olmsted (Am. Journal of Science, vol. xxvi, p. 155) for estimating the diameter of meteors on comparison with the moon.

† It ought however to be stated, that in the paper above referred to, Mr. Herrick expressly mentioned this and other sources of fallacy, endeavored as far as practicable to guard against them, and gave his final careful result as necessarily open to some uncertainty.—Eds.

not have had less than six or seven hundred miles of atmosphere to traverse, before it reached the limit of that medium; it has already acquired a state of ignition in its passage through the air prior to the explosion, and should have retained its luminous appearence consequent thereupon, at least while remaining in the atmosphere: but as this was not the case, and a sudden disappearance of the entire body took place in the very lowest portions of the atmosphere, and descending luminous fragments were seen, the natural conclusion appears to be, that the whole meteorite was contained in the fragments that fell.

As to the Weston meteorite, it is stated that its direction was nearly parallel to the surface of the earth at an elevation of about 18 miles; was one mile farther when it exploded; the length of its path from the time it was seen until it exploded was at least 107 miles; duration of flight estimated at about 30 seconds, and its relative velocity three and a half miles a second; it exploded; three heavy reports were heard; *the meteorite disappeared at the time of the explosion.*

As to the value of the data upon which its size was estimated, the same objection is urged as in the case of the Wilton meteorite; and it is hazarding nothing to state that the apparent size may have been due to an incandescent body a foot or two in diameter. Also, with reference to its disappearance, there is the same inexplicable mystery. It is supposed from its enormous size that but minute fragments of it fell; yet it disappeared at the time that this took place, which it is supposed occurred 19 miles above the earth, (an estimate doubtless too great when we consider the heavy reports). Accepting this elevation, what do we have? A body one mile and a half in diameter in a state of incandescence, passing in a curve almost parallel to the earth, and while in the very densest stratum of air that it reaches with a vigorous reaction between the atmosphere and its surface, and a dense body of air in front of it, is totally eclipsed; while, if it had a direction only tangential to the earth, instead of nearly parallel, it would at the height of 19 miles have had upwards of 500 miles of air of variable density to traverse, which at the relative velocity of $3\frac{1}{2}$ miles a second (that must have been constantly diminishing by the resistance) would have taken about 143 seconds. It seems most probable that if this body was such an enormous one, that it should have been seen for more than ten minutes after the explosion, for the reasons above stated. The fact of its disappearance at the time of the explosion, is strong proof that the mass itself was broken to fragments, and that these fragments fell to the earth;—assuring us that the meteorite was not the huge body represented, but simply one of those irregular stony fragments which, by explosion from heat and great friction against the atmosphere, become shattered. I say irregular, because we have strong evidence of this irregularity, in its motion, which was

"scolloping," a motion frequently observed in meteorites, and doubtless due to the resistance of the atmosphere upon the irregular mass; for a spherical body passing through a resisting medium at great velocity would not show this. In fact, if almost any of the specimens of meteorites in our cabinets were discharged from a cannon, even in their limited flight the scolloping motion would be seen.

This then will conclude what I have to say in contradiction to the supposition of large solid cosmical bodies passing through the atmosphere, and dropping small portions of their mass. The contradiction is seen to be based; first, upon the fact that no meteorite is known of any very great size, none larger than the granite balls to be found at the Dardanelles along side of the pieces of ordnance from which they are discharged; secondly, on the fallacy of estimating the actual size of these bodies from their apparent size; and lastly from its being opposed to all the laws of chance that these bodies should have been passing through an atmosphere for ages and none have yet encountered the body of the earth.

To sum up the theory of the lunar origin of meteorites, it may be stated—*That the moon is the only large body in space of which we have any knowledge, possessing the requisite conditions demanded by the physical and chemical properties of meteorites; and that they have been thrown off from that body by volcanic action, (doubtless long since extinct,) and, encountering no gaseous medium of resistance, reached such a distance as that the moon exercised no longer a preponderating attraction—the detached fragment, possessing an orbital motion and an orbital velocity, which it had in common with all parts of the moon, but now more or less modified by the projectile force and new condition of attraction in which it was placed with reference to the earth, acquired an independent orbit more or less elliptical. This orbit, necessarily subject to great disturbing influences, may sooner or later cross our atmosphere, and be intercepted by the body of the globe.*

In concluding this lengthy examination, I must say that a discussion of the phenomena accompanying the falling of meteorites has been avoided, as well as many points connected with their history. This has been done from its having no immediate connection with the object of this memoir, which is intended simply to present to the Association some new views, and many old views in a new light; so as to awaken attention to the study of this most interesting class of bodies.

I take pleasure in acknowledging my obligations to the Secretary of the Smithsonian Institution, for the ready manner in which he placed the Laboratory of that Institution at my disposal for the purpose of making the analytical investigations, contained in this memoir, as well as other researches yet unpublished.

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